The MoonTWINS Mission Concept : an Affordable and Science Attractive European Mission to validate MSR Soft Landing and Hazard Avoidance Technologies

5th International Planetary Probe Workshop, June 25, 2007

Pascal Regnier, Astrium Satellites Toulouse

All the space you need

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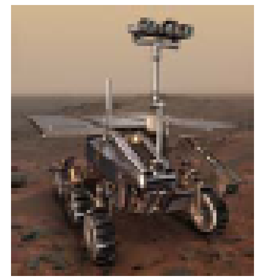
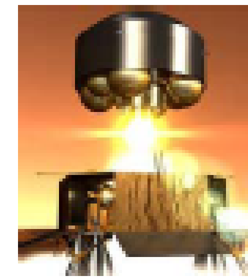
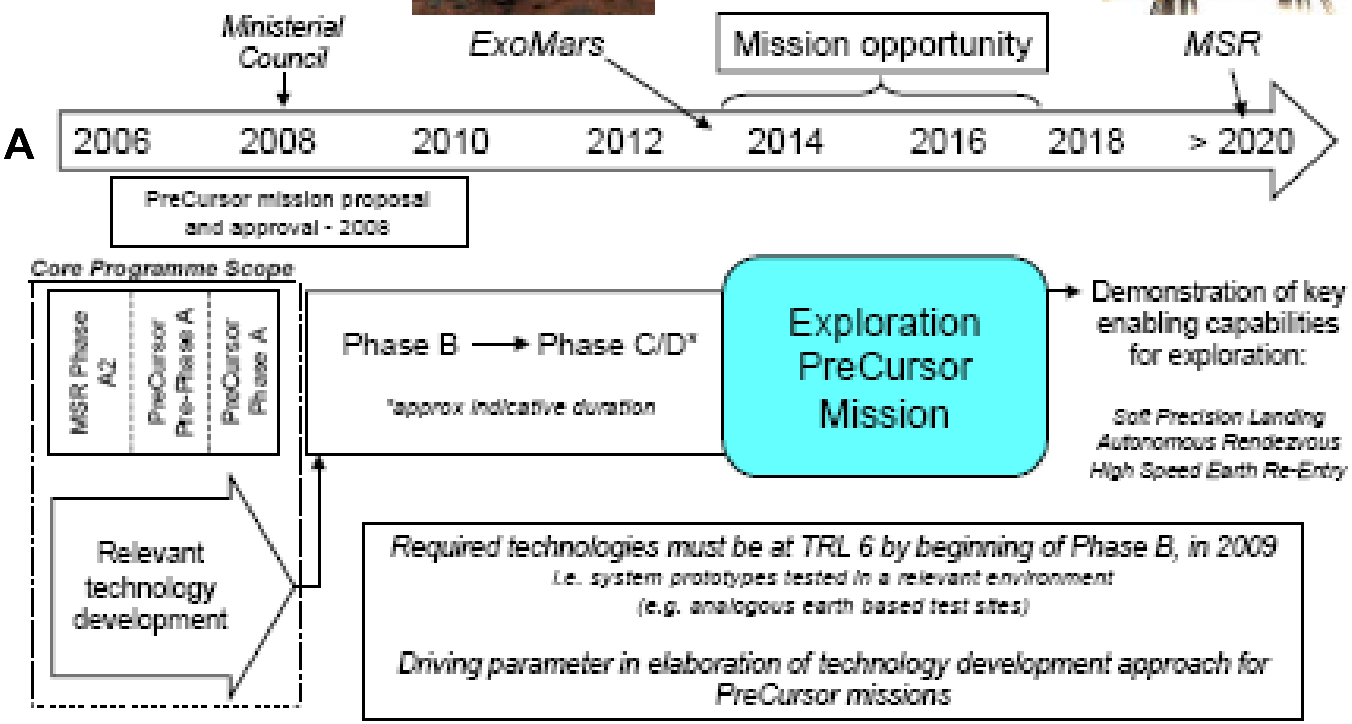
MoonTWINS Mission Context

- one of the four MSR Pre-cursor pre-phase A studies within TAS-I led MSR Phase A2 (selected by ESA after competition)
- to be combined with ESA assessment studies of two mission concepts from the Aurora Call for Ideas (NEXT missions)





- two missions to be selected for industrial Phase A studies in 2008
- MSR precursor mission to be decided at the 2008 Ministerial Council
- launch around 2015

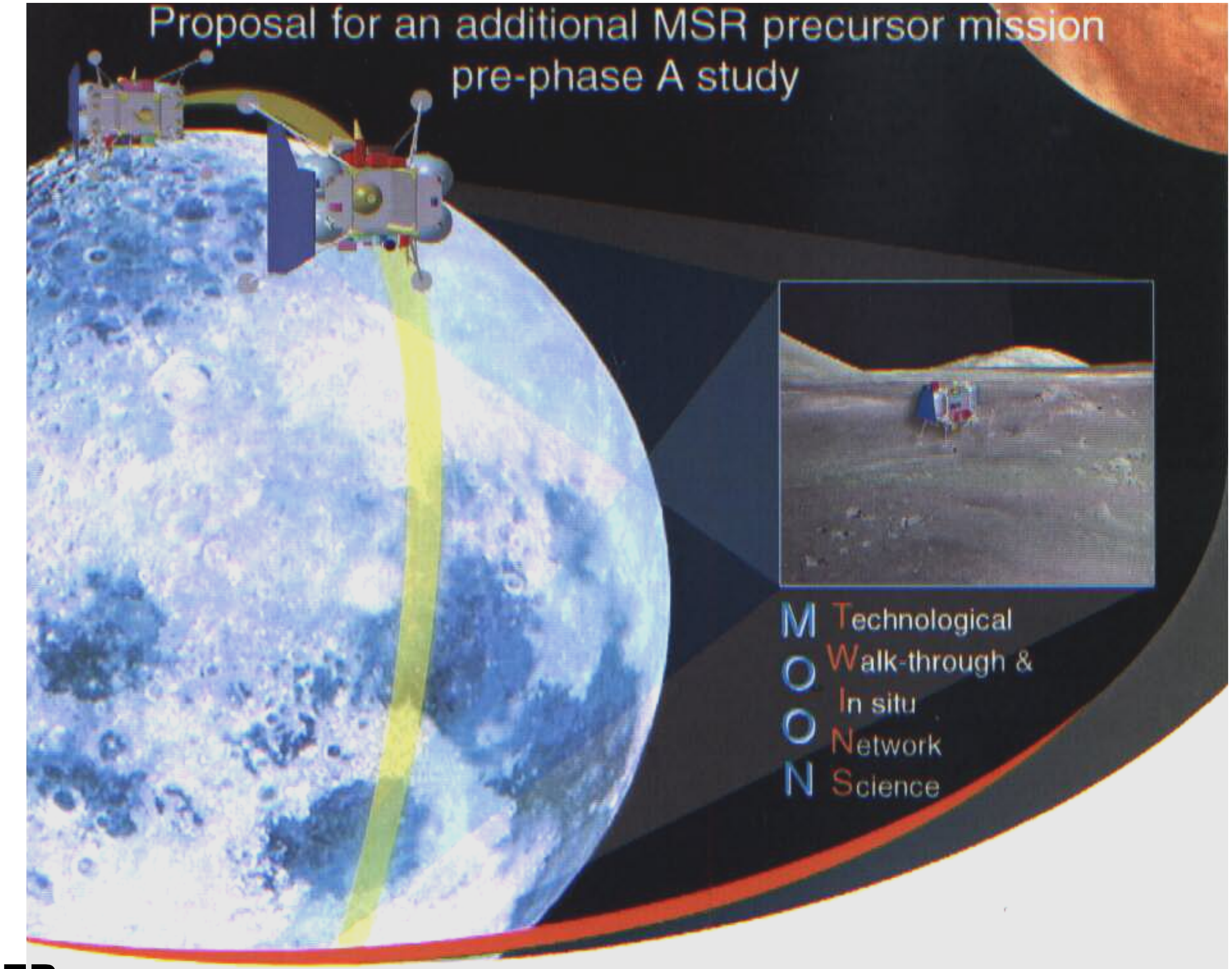


MSR Precursor Mission Context

- **Mission primary objectives = validate key MSR technologies, especially :**
  - o Planetary Entry, Descent and Soft Precision Landing
  - o Planetary Ascent
  - o Autonomous RendezVous and Docking / Capture
  - o Sample Collection
  - o High Speed Earth Re-entry
  - o Sample Recovery
- **Secondary objective = Science, with potential targets :**
  - o Earth
  - o Moon
  - o Near Earth Object
  - o Phobos
- **Mission CaC must be below 400 M€ (incl. launch and operations)**

The MoonTWINS Mission Concept

- **launched by Soyuz-Fregat 2.1b from Kourou**
- **two quasi-identical spacecraft for:**
  - demonstration of autonomous RV in Moon orbit
  - soft and precision landing, vision-based and LIDAR navigation with hazard avoidance
  - support long-term science network mission on the Moon surface
  - prepare the Moon manned exploration by being potentially the first lander at the South Pole Peak of Eternal Light
  - NASA-like dual spacecraft mission concept (Viking, Voyager, MER)
- **Astrium teaming with SENER, Deimos, IPGP and DLR**



Science at the Moon

- **the Moon has become a priority target destination for almost all agencies**

Selene	Japan	summer 2007	just orbiter	ready for launch since 2005	Dec 2006
Selene-2	Japan	2012	landing at tbd site	proposal/vision	Dec 2006
Selene-3	Japan	201x	landing at tbd site	proposal/vision	Dec 2006
Lunar-A	Japan	2010		cancelled since Jan 2007	janv-07
Chang'E Lunar 1	China	2007	just orbiter	tests since July 2006	juil-06
Chang'E Lunar 2	China	2008	orbiter	vague, not serious	?
Chang'E Lunar 3	China	2009	orbiter	vague, not serious	?
Phase 2 lander	China	2012	rover: site tbd after first mission	planned	juin-06
Phase 2 sample return	China	2017	sample return; site not defined	planned	juin-06
Chinese Human Moon mission	China	NET 2024	tbd site	planned, intended	juin-06
Luna-Glob	Russia	2012	Aitken crater	study phase, intended	
Chandrayyan-1	India	1.Q/2008	polar mapping	under development	04/01/07
Chandrayyan-2	India	2010-11	rover: site to be determined after first mission	planned	04/01/07
Lunar Reconnaisance Orbiter (LRO) + LCROSS	USA	oct-08	orbiter + impactor on South pole crater	under development	juil-06
CEV-X	USA	NET 2018	human landing	firm planning	
Robotic Lunar Exploration Programme RLEP-2	USA	NET 2011	South pole crater	early formulation stage	Jan/ 07
Moon orbiter	Germany	NET 2011	just orbiter	idea and intention	janv-07
tbd	Italy	NET 2011	most probably orbiter if any	studies and intention	janv-07
MoonLITE	UK	NET 2011	orbiter + penetrators	conceptual studies but no planning	janv-07
Moon Raker	UK	NET 2013	landing at tbd site	conceptual studies but no planning	janv-07

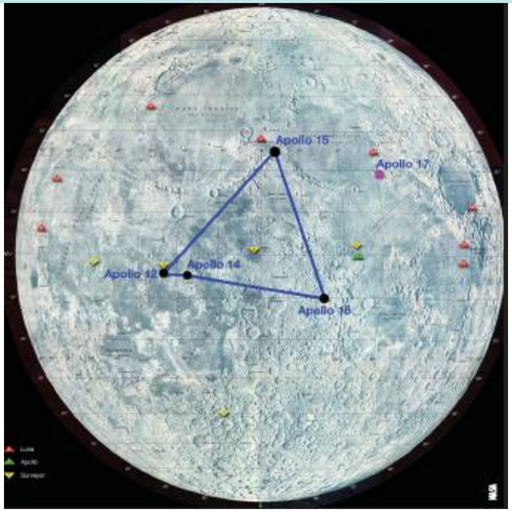
- **but no robotic soft landing mission in development yet !**
- **with MoonTWINS, ESA could well be the first agency to return to the Moon surface, and the first one to land at the South Pole Peak Of Eternal Light in 2015**

Science at the Moon

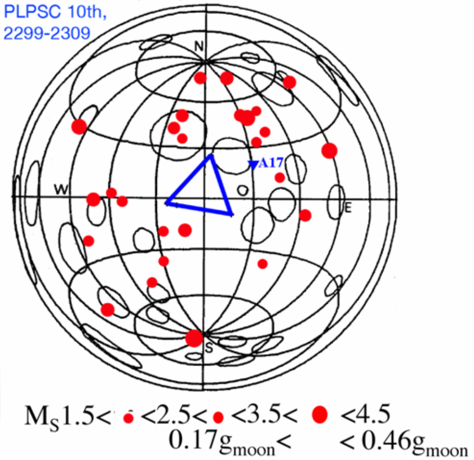
- **Yet unanswered questions about the Moon**
  - o Moon interior and structure mechanisms: quakes mechanism and risks, meteorites impacts, deep interior characterisation (today's sensors are 100x more sensitive than the Apollo seismometers)
  - o Dynamics of Earth / Moon system: test the equivalence principle, refine Earth/Moon parameters knowledge (nutation, precession)
  - o Refine Crustal and Regolith structure
  - o Interaction of the Earth magnetotail and solar wind with the Moon
  - o Geochemistry / mineralogy : more related to either rover / sample return

- **Science from the Moon**
  - o Derisk a future radio-astronomy interferometer: assess sensors needs and techniques, characterise radio-electrical environment.

Apollo missions seismic network

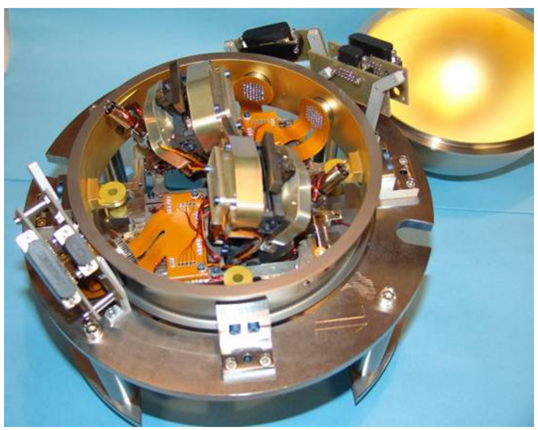


Nakamura et al. (1979)
PLPSC 10th,
2299-2309



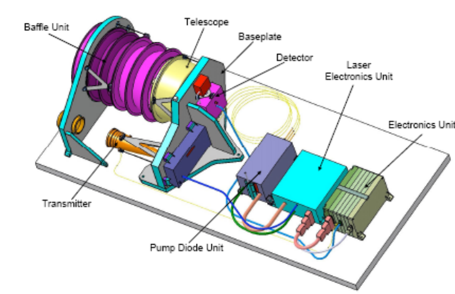
Proposed MoonTWINS Science Payload (to be re-visited with ESA during the study)

- **~20 kg scientific package based on already mature designs :**
  - Primary payload: Very broad Band seismometers deployed at the South Pole and Northern hemisphere to explore the Moon deep interior (Mars 96, Netlander, GEP heritages)
  - Secondary (to be confirmed with ESA): environment sensors package mounted on a mole (HP3 – Heat Flux and Physical properties Measurements) for characterisation of some key geo-science parameters, Geodesy Experiment (passive reflector, Laser transponder or radio-interferometry) for the dynamics of Earth / Moon system, magnetometer, radiation sensor, radio-astronomy precursor experiment…
  - Local site mapping cameras: based on Rosetta lander cameras



SEIS bread-board developed for Mars 96 by IPGP/CNES/SODERN. Concept further refined for Exomars (GEP)

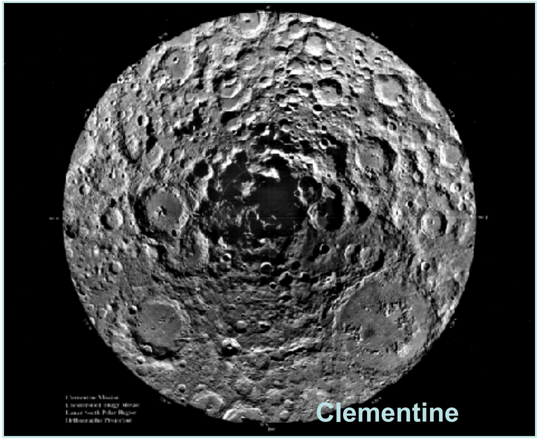
DLR mole bread-board, its payload compartment and tether

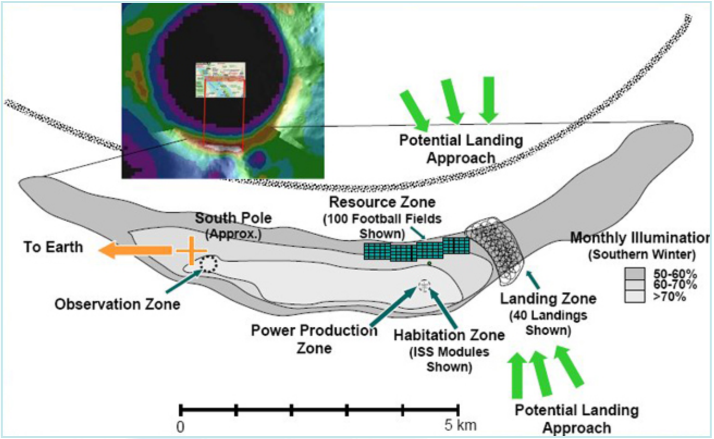


Bepi-Colombo BELA instrument

MoonTWINS : preparing the future Manned Exploration of the Moon

- **December 2006 NASA announcement: return to the Moon no later than 2020!**
  - locate an outpost near one the pole region (uniform temperatures, ~permanent lighting conditions, in-situ resources nearby (water ice in permanently shadowed craters)
- **A tremendous opportunity for MoonTWINS polar lander**
  - Better understand potential quakes and meteorites hazards
  - Help choosing the best support soil for building infra-structure and identify in-situ resources
  - Complete LRO mapping data and optimise outpost location
  - Precisely assess lighting conditions
  - Validate soft landing GNC for big cargo landers
  - Raise the first flag on a Peak of Eternal light !!!

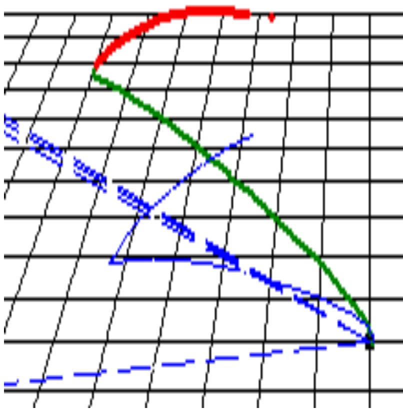


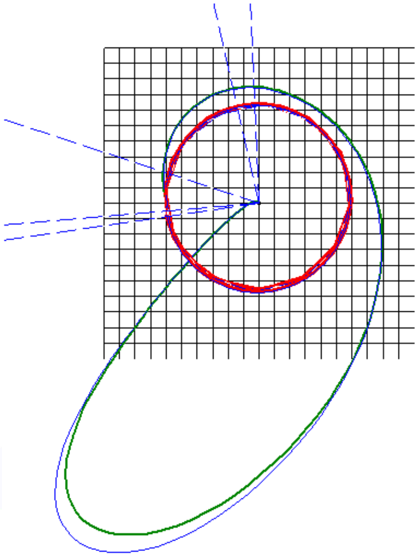


One favourite site for a lunar base is at the Moon's south pole - a strategic locale on the rim of Shackleton Crater that's almost permanently sunlit.

MoonTWINS Mission Analysis and Architecture Trade-offs

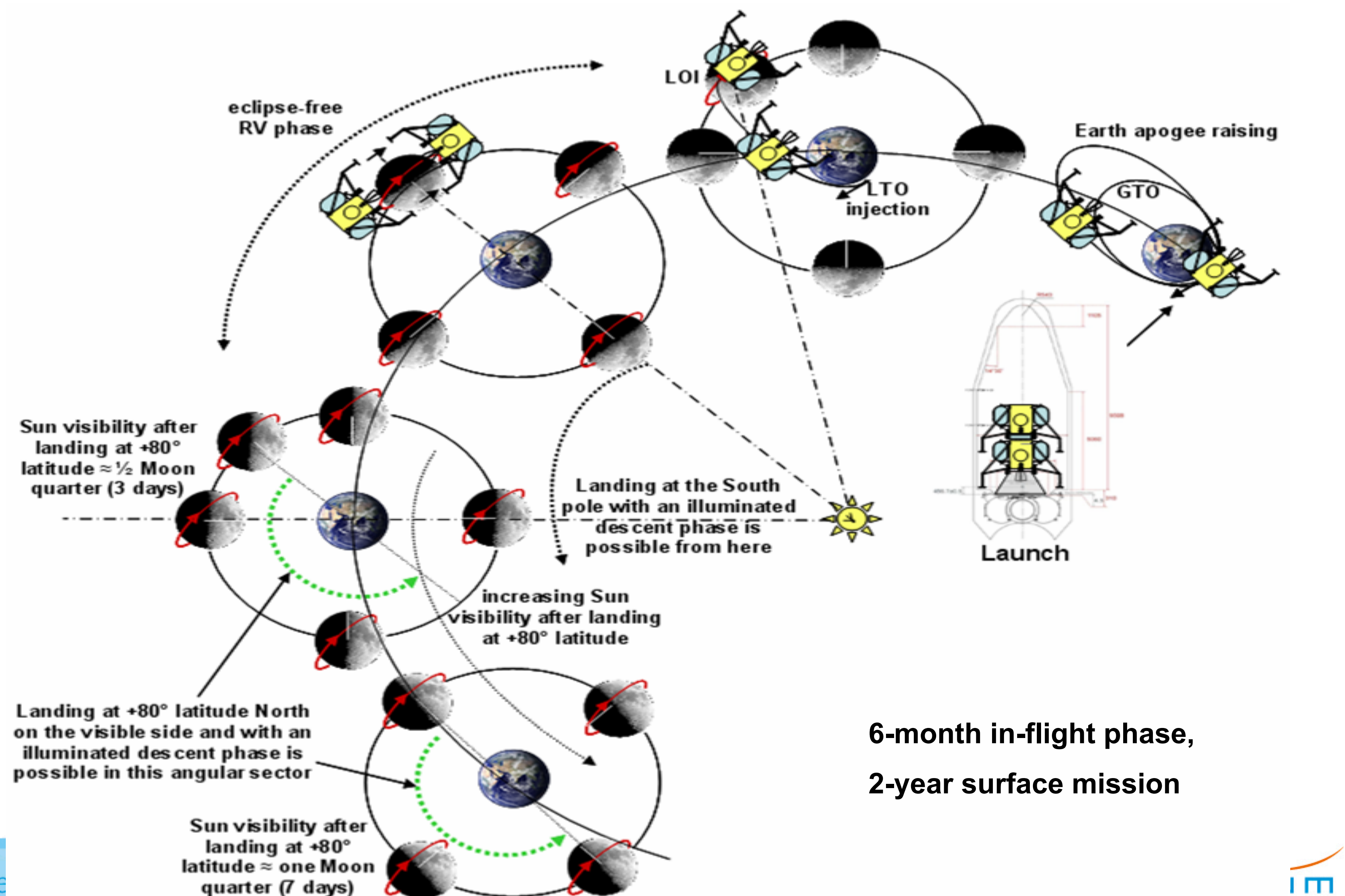
- **Launch strategies :**
  - o Soyuz-Fregat direct injection in LTO
  - o Soyuz-Fregat GTO-like orbit injection (higher mass performance)
  - o Ariane 5 shared GTO commercial launch as an option
- **Transfer strategies :**
  - o 5-day conjunction type transfer
  - o 100+ days Weak Stability Boundary transfer
- **Mission architecture trade-offs :**
  - o Launch and transfer strategies, propulsion stage or not





	S-F launch in LTO	S-F launch in GTO	S-F launch in GTO	Shared Ariane 5 commercial GTO launch
Launch performance	~2100kg (incl adapter)	~3060kg (incl adapter)	~3060kg (incl adapter)	typ. ~4000kg (without adapter)
Staging approach	No propulsion stage	No propulsion stage	LISA-Pathfinder like propulsion stage	No propulsion stage
ΔV to Lunar Circular Orbit	~900m/s	~1600m/s	~1600m/s	~1600m/s TBC
Mass in Lunar orbit	2 x ~750kg	2 x ~900kg	2x ~800kg +200kg (LISA-PF)	2x ~1200kg
ΔV to Lunar surface	~1900m/s			
Lander dry mass allocation	**~380kg each**	**~450kg each**	**~400kg each**	**~600kg each**
Lander propellant capacity requirement	**~650kg each**	**~1050kg each**	**~400kg each**	**~1400kg each**
Mission Costs	**lowest**	**lowest**	**+ a few tens of MEuro**	**+ a few tens of MEuro**
Mission complexity and risks	**lowest**	**lowest**	**More complex composite spacecraft**	**More complex trajectory design**

MoonTWINS Overall Mission Sequence

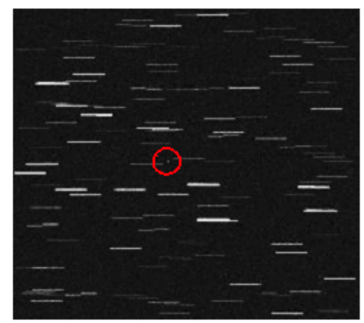


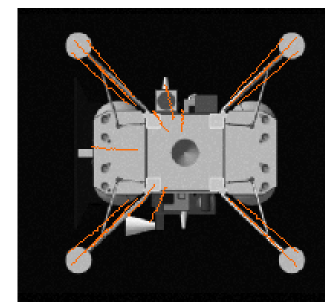
6-month in-flight phase,

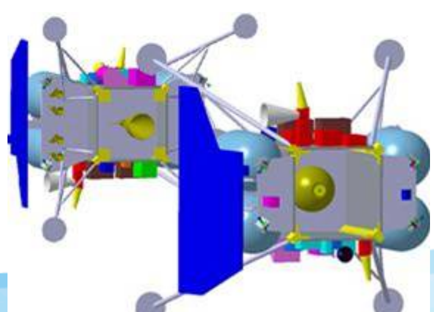
2-year surface mission

Automatic Rendez-vous demonstration

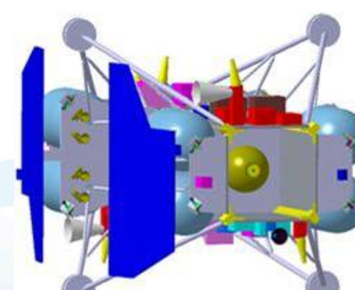
- **Objectives**
  - o validate RV technologies, GNC algorithms and operations required for MSR docking or capture in representative orbit kinematic conditions
  - o but with much more operational flexibility and safety (no round trip delay, omni-directional TM, high data rate)
  - o use of representative RV mechanisms depending on launch mass assessment
- **Baselined RV technology (same as for landing)**
  - o Vision-based navigation : ESA HARVD study heritage
  - o LIDAR (on one lander) : ESA LiGNC study heritage
- **RV phases :**
  - o Target detection and acquisition (50-200km)
  - o Intermediate rendez-vous phase (down to a few km)
  - o Terminal RV : touch-and-go manoeuvre





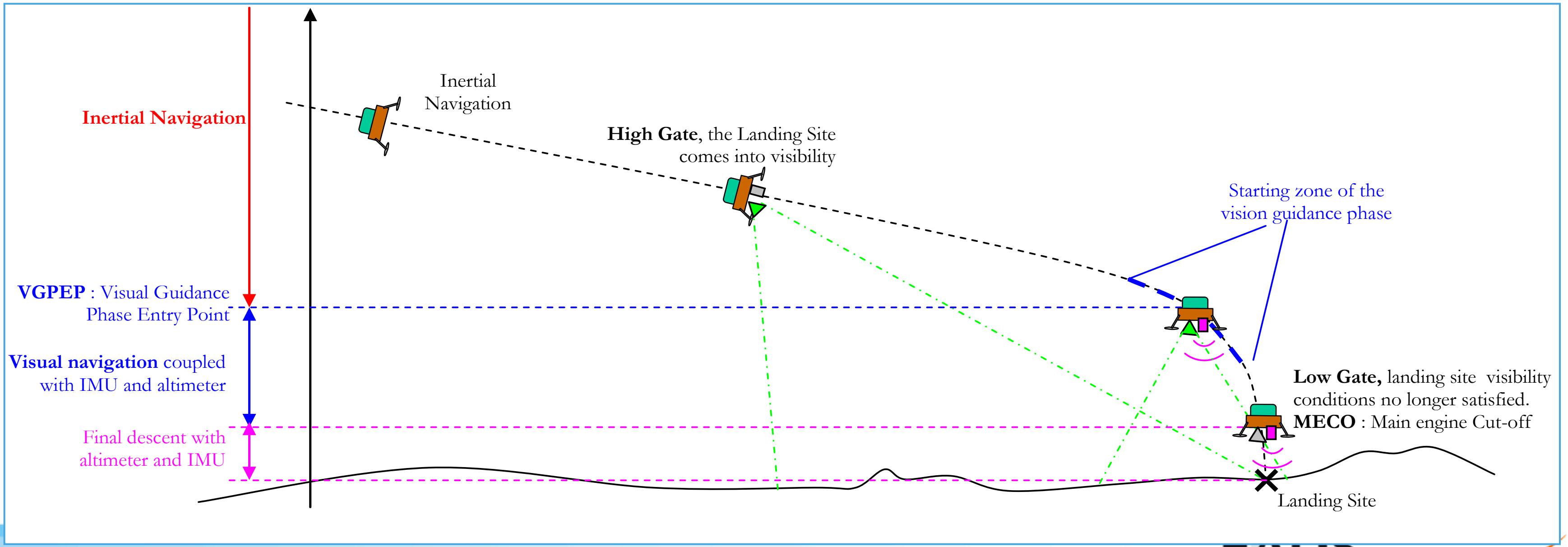


landing legs footpads used at contact



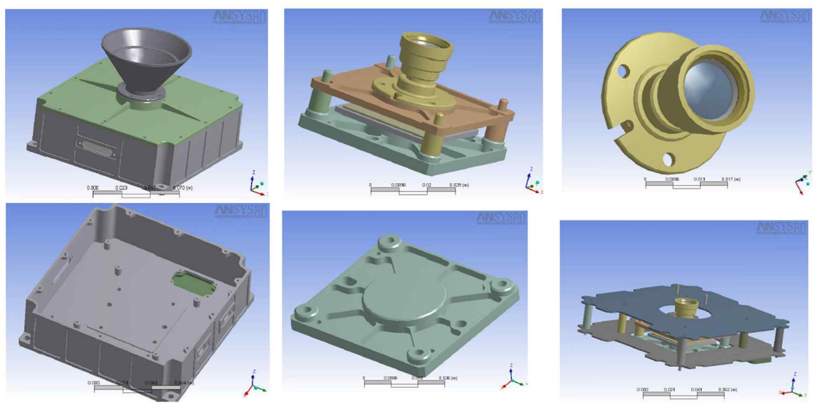
Soft / Precision Landing

- **Objectives**
  - o successfully achieve first European soft landing (GNC + legs)
  - o demonstrate vision-based navigation and LIDAR navigation (the two soft landing technologies under pre-development at ESA)
  - o demonstrate precision landing through image correlation techniques (not required on MSR)
  - o demonstrate hazard avoidance capability (using optical camera and LIDAR)
  - o in MSR representative trajectory conditions : vertical descent at ~1km altitude

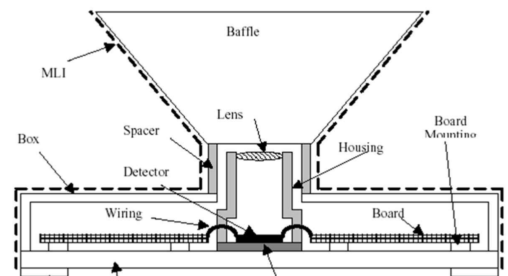


Soft / Precision Landing

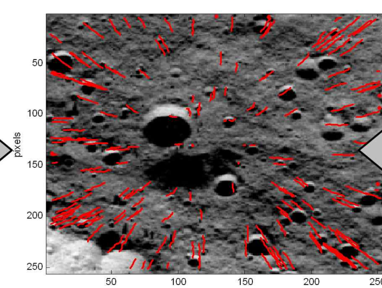
- **Vision-based navigation**
  - o based on NPAL study heritage : a technological breakthrough for Vision-based Navigation (ESA science Critical Technologies Program, 2001-2006)
  - o breadboard camera and image processing / navigation algorithms now qualified in real-time environment (TRL 4-5)
  - o soon to be tested on the ESA Precision Landing GNC Test Facility (TRL 5-6)
  - o assisted by radar altimeter for robustness / faster convergence
  - o light weight / low cost

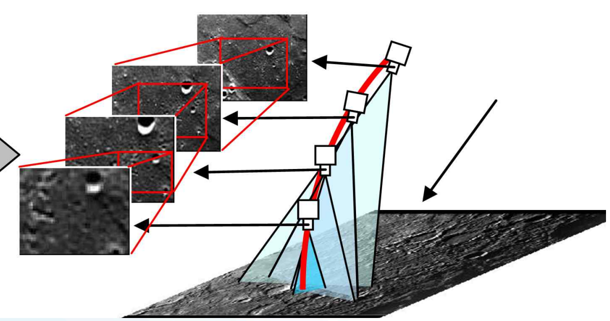


Some elements of the structural models



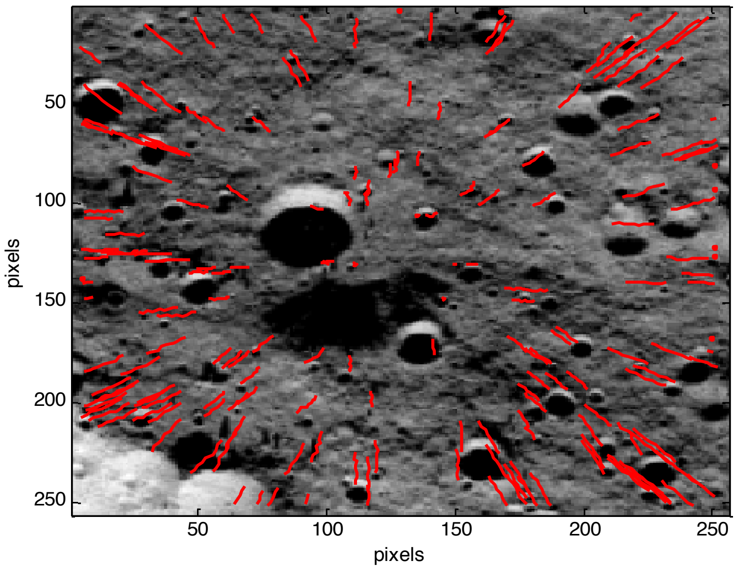
Thermal model

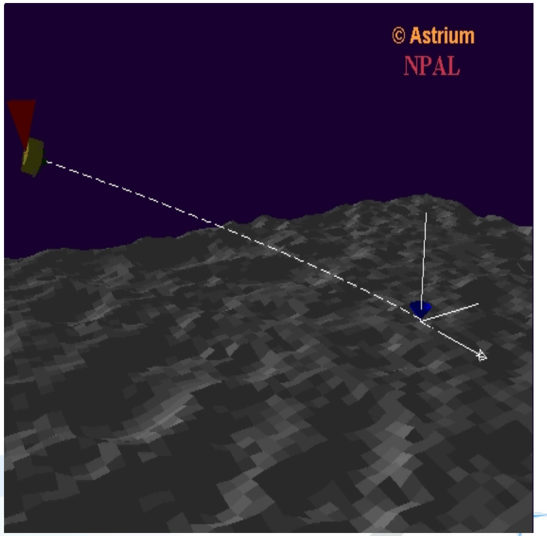




NPAL Concept

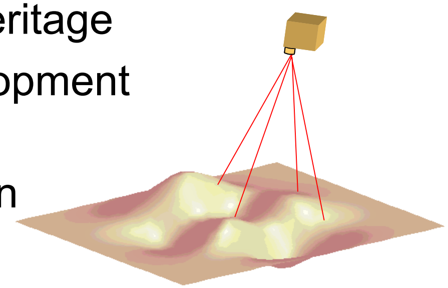
- **Based on the extraction of Feature Points in the picture**
- **Feature points are tracked from one picture to the following one, using a specialized image processing**
- **Tracks of positions are processed by a customized Adaptive Kalman filter**
  - Vehicle state derivation is based upon primary points tracking
  - Secondary points are used for terrain 3D reconstruction
- **NPAL allows for “Soft & Safe” landing in unknown environment**

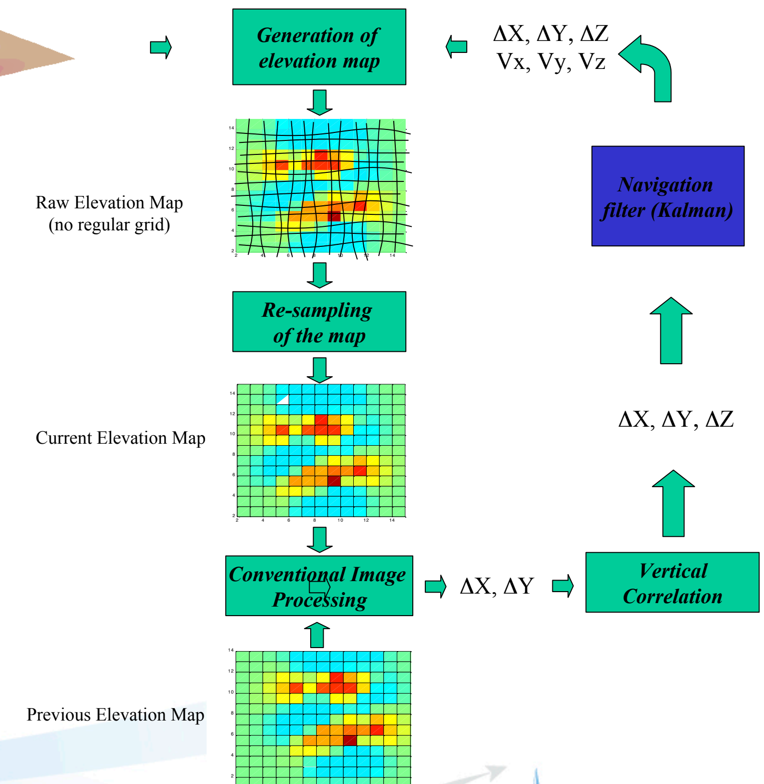


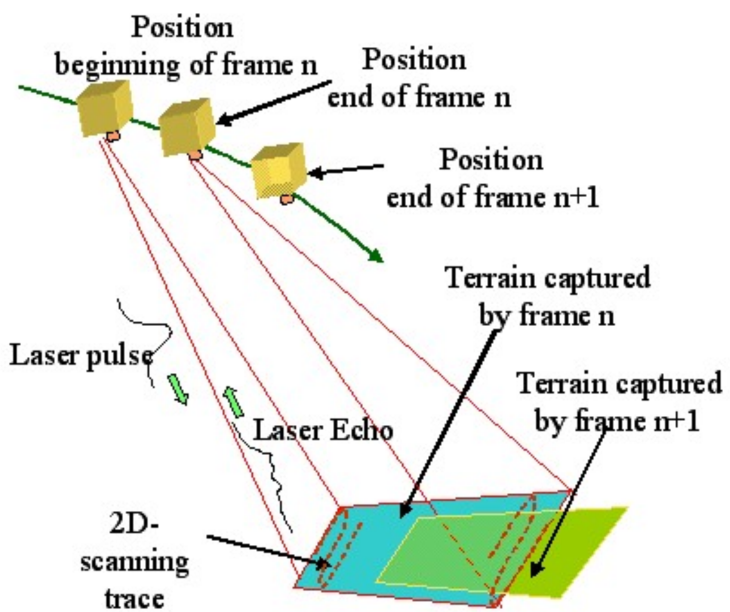


Soft / Precision Landing

- **LIDAR navigation**
  - o based on LiGNC study heritage
  - o LIDAR breadboard development on-going in Europe
  - o more robust to illumination conditions than vision navigation
  - o used at short ranges only
  - o heavier, power hungry

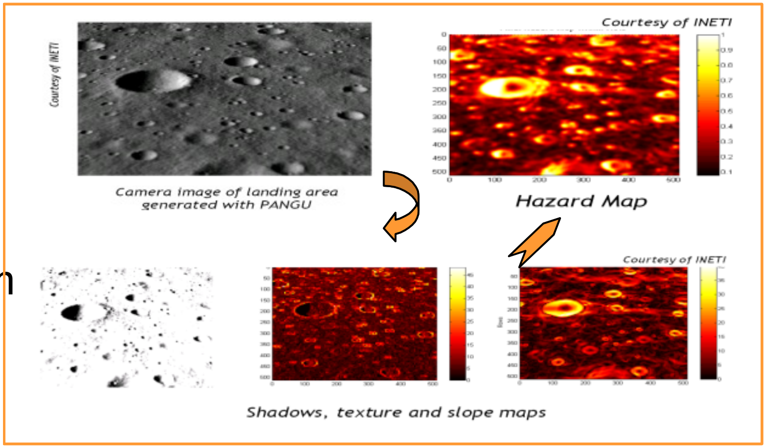


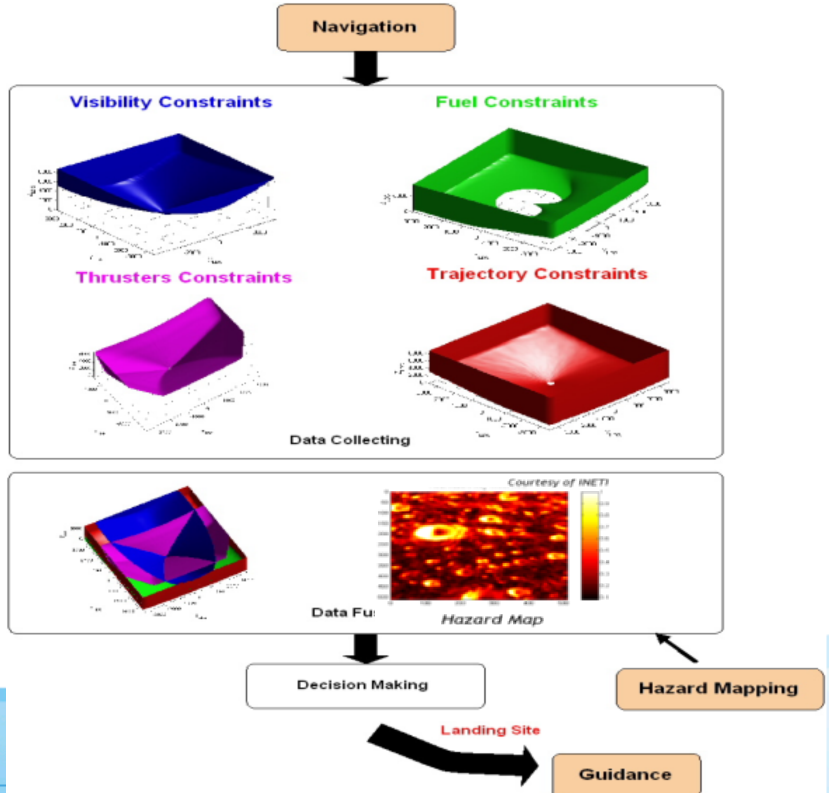


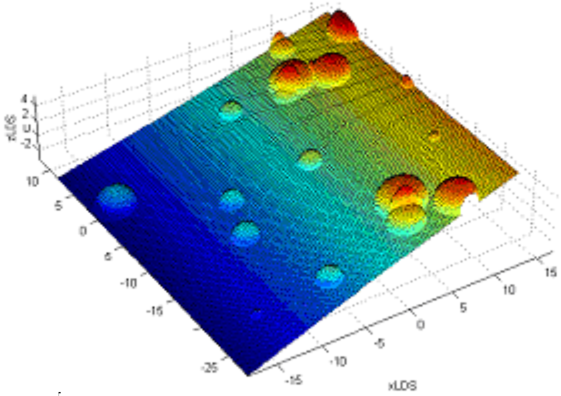


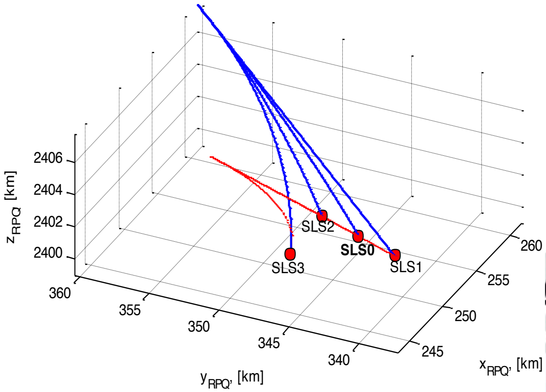
Soft / Precision Landing

- **Hazard Avoidance**
  - o based on vision or LIDAR (LIDAR preferred at grazing Sun incidence angles)
  - o hazard mapping and re-targeting in the last km
  - o very strong background and heritage at Astrium and Deimos (VBRNAV)



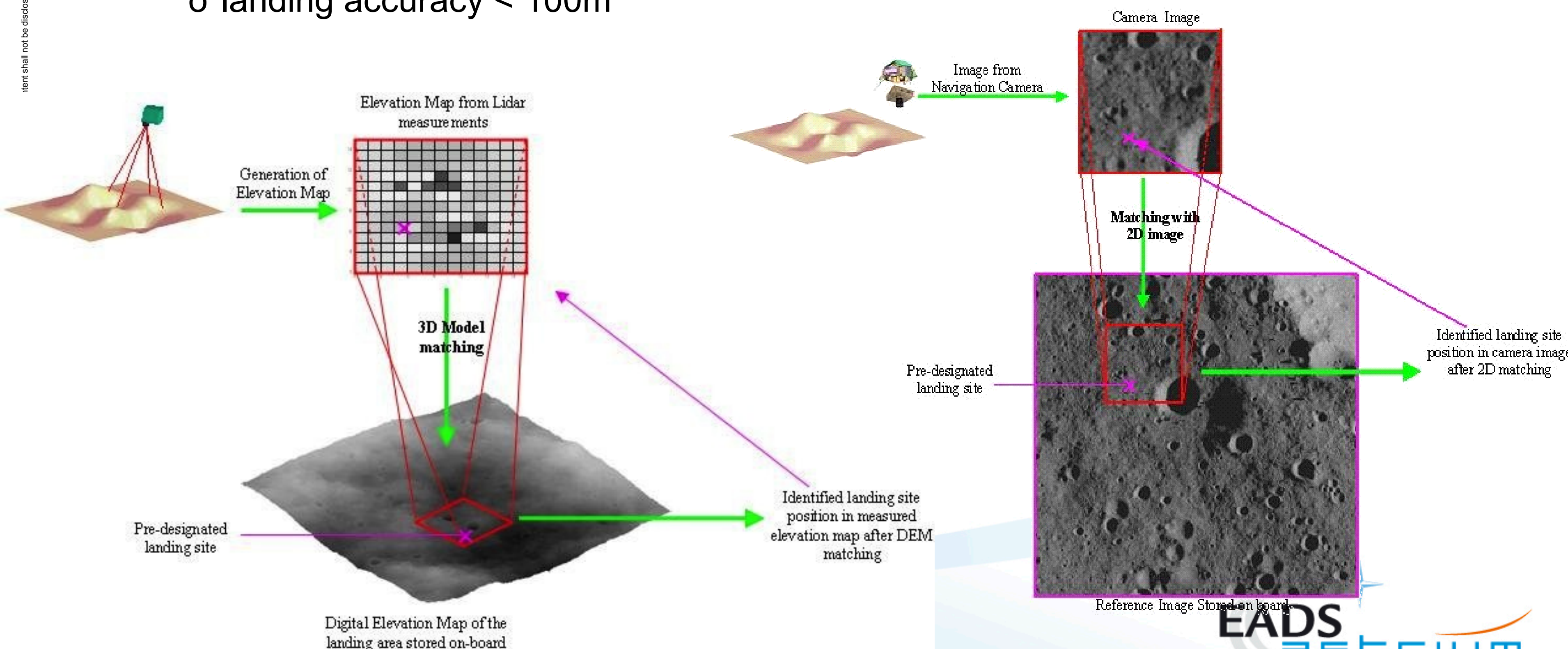






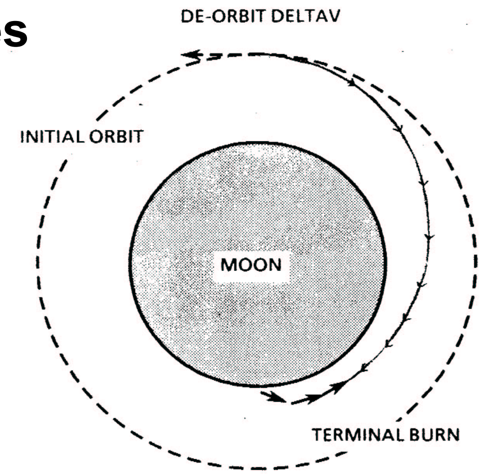
Soft / Precision Landing

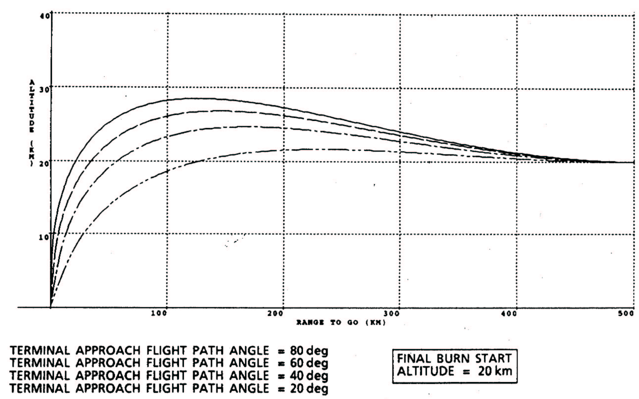
- **Precision landing**
  - o based on image correlation techniques
  - o Heritage from the on-going Optical Flow Navigation System for Landing ESA study
  - o needs and on-board DEM or 2D terrain model of the landing area
  - o landing accuracy < 100m



Soft / Precision Landing

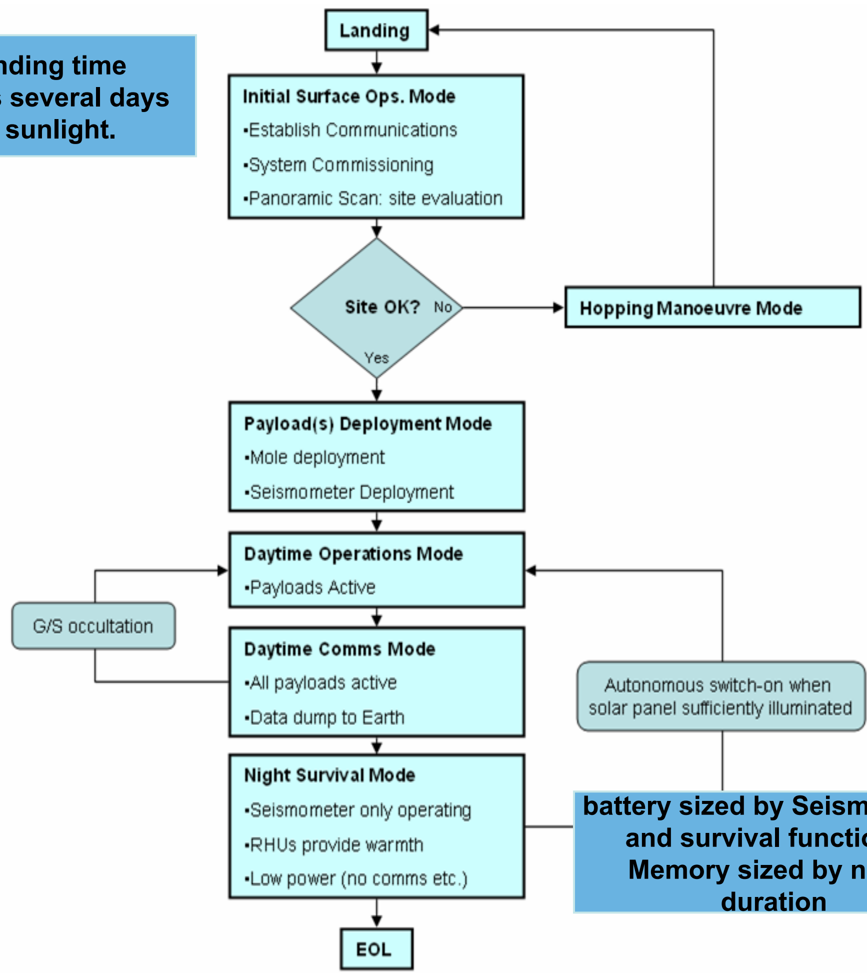
- **Trajectory Guidance & Control and Propulsion issues**
  - o near optimal descent trajectory
  - o navigation rehearsal possible in intermediate orbit
  - o Apollo-like Gravity Turn or Modified Bilinear Tangent Law guidance strategy (trade-off wrt precision landing, hazard avoidance, fuel consumption, on-board implementation)
  - o propulsion system based on one EADS-ST 500N main engine and eight ATV-derived 250N thrusters
    - – currently in development / qualification
    - – highly efficient and flexible thrust / mass ratio
    - – large control capacity through PWM of 250N thrusters



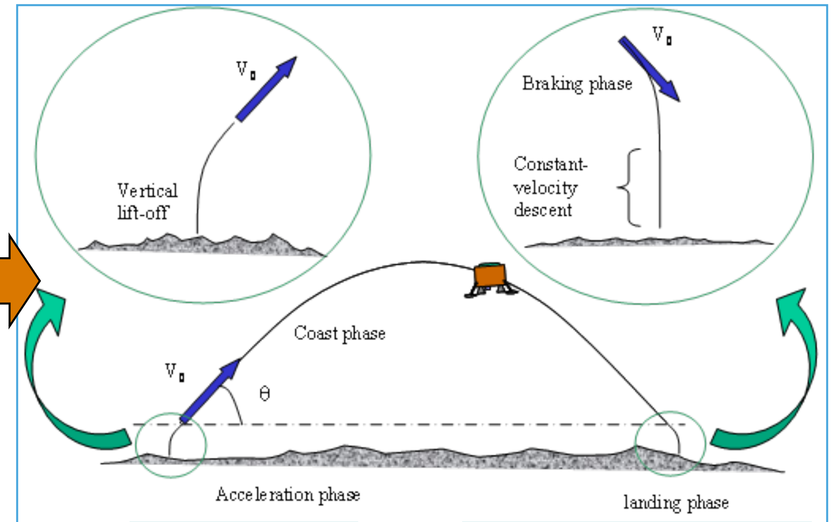


On-surface mission

Landing time allows several days in sunlight.



battery sized by Seismometer and survival functions. Memory sized by night duration



IMU guidance 8x250 N thrusters

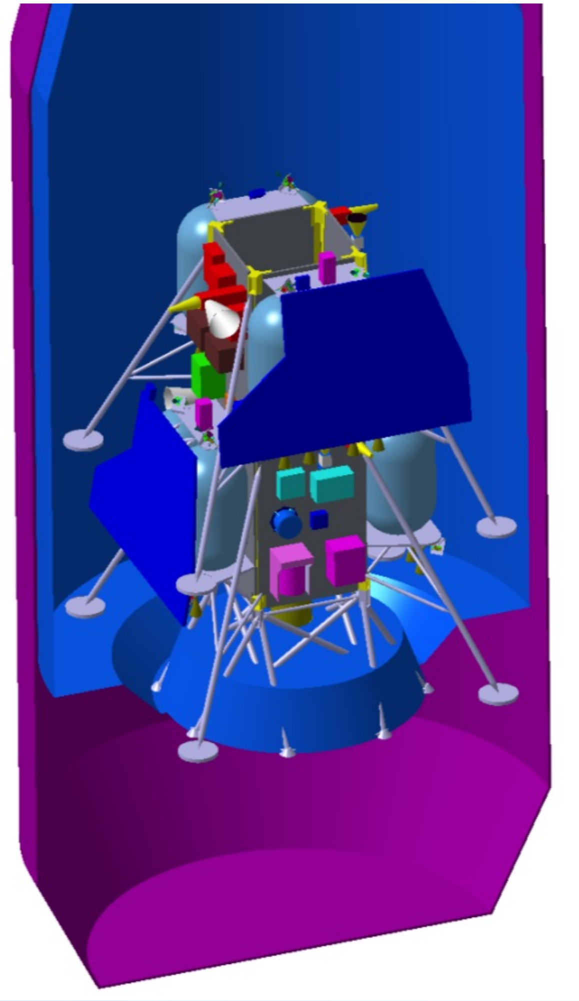
IMU or optical guidance 8x250 N thrusters

Hopping only if enough propellant remaining on surface (margins). Necessitates precise propellant measurement devices. Feasible by both landers.

System Design

- **Spacecraft Configuration**

S-F ST fairing



Cluster-like
separation strategy

Launch mass :
3060kg in GTO

System Design

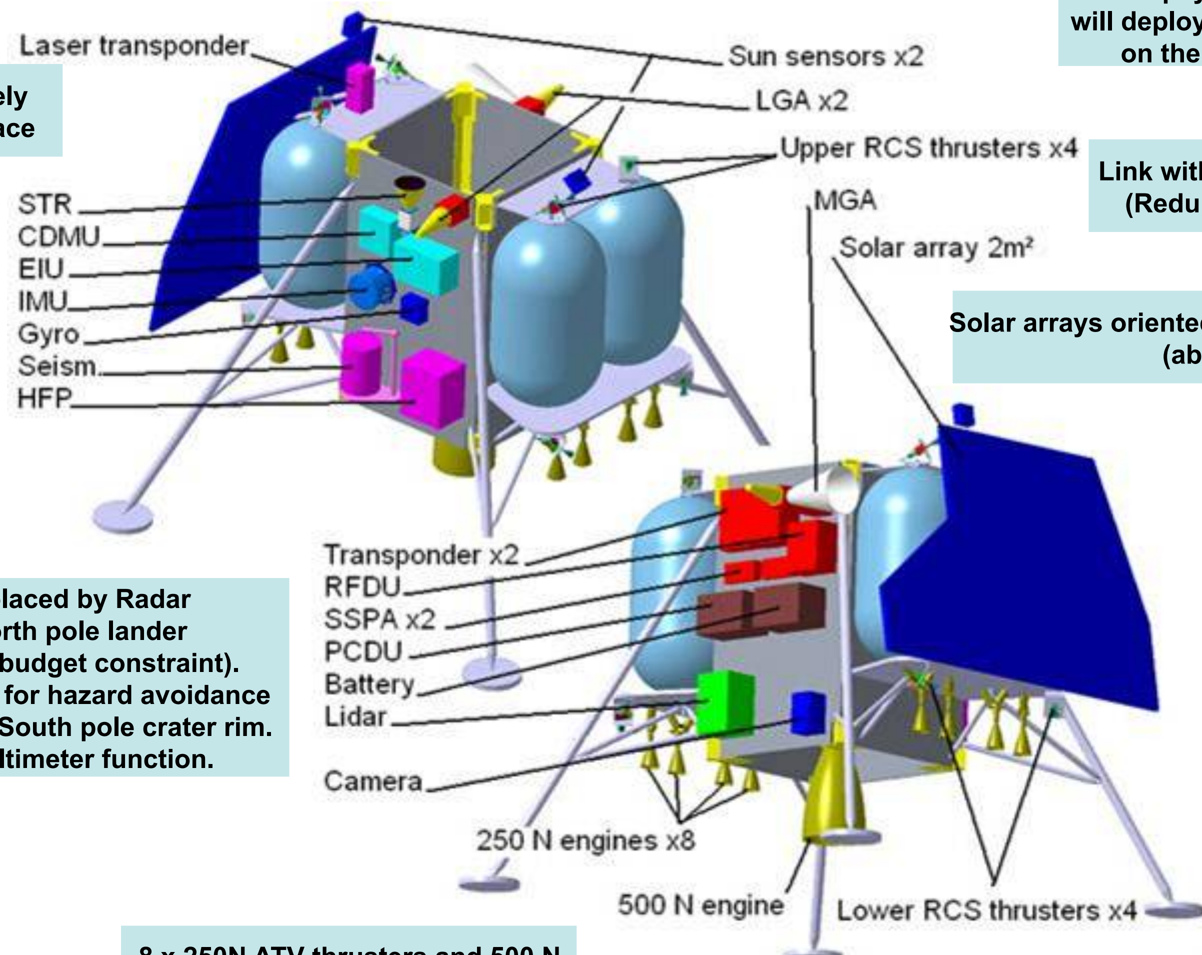
▪ Spacecraft Configuration (under consolidation)

Stowed payload state: an arm will deploy the seimosmeter on the moon surface

Two crafts fly separately all the way to the surface

Link with ESTRACK 15m stations (Redu, Vilspa, Kourou, Perth)

Solar arrays oriented for high Moon latitudes (above 80°)



LIDAR replaced by Radar for the North pole lander (overall mass budget constraint). Lidar necessary for hazard avoidance when landing at South pole crater rim. Both have altimeter function.

8 x 250N ATV thrusters and 500 N apogee engine used for descent and landing phase

System Design

- **Major system design drivers :**
  - o GNC and propulsion configuration : highly efficient bi-liquid system, 6dof RCS configuration for RV and landing
  - o on-surface thermal control drives the night power budget. RHUs might be required (ExoMars follow-on procurement)
  - o solar array and battery sizing : assumes at least seismometer operations at night, depends on selected landing site latitude
  - o avionics : based on compact new generation LEON-based avionics
  - o FDIR / redundancy : minimum level of redundancy implemented to secure the safe mode in case of failure / anomaly. Mission redundancy is provided by the one+one landers
  - o Seismometer deployment mechanism : small crane or cable lift
  - o mass minimisation : CFRP structure, lightweight landing legs

Conclusions

- **MoonTWINS is a science attractive and affordable mission concept candidate for ESA MSR pre-cursor mission selection**
- **Moon Science objectives focused on geophysics, secondary objectives being consolidated with ESA**
- **Unique opportunity for ESA to prepare the Moon manned exploration (first lander at the South Pole PEL in 2015 ?)**
- **MSR technology demonstration objectives focused on vision-based and LIDAR navigation, for soft landing and RV**
- **Mission and system design, landing sites and science payload being consolidated in the current study until September**

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